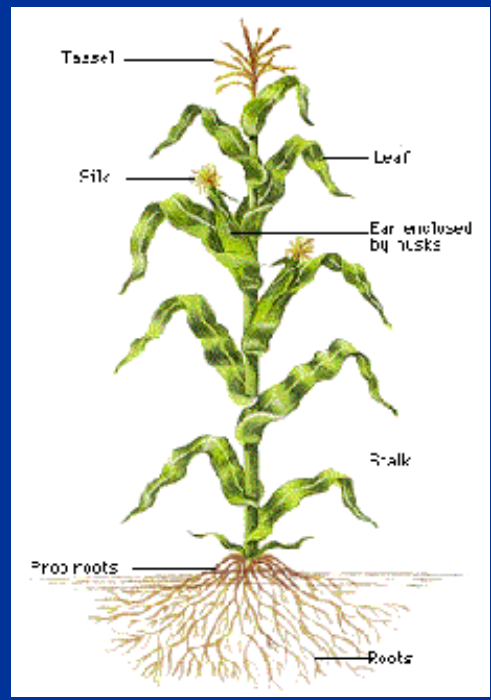
National Renewable Energy Laboratory

Causes and Effects of Variation in Corn Stover Composition



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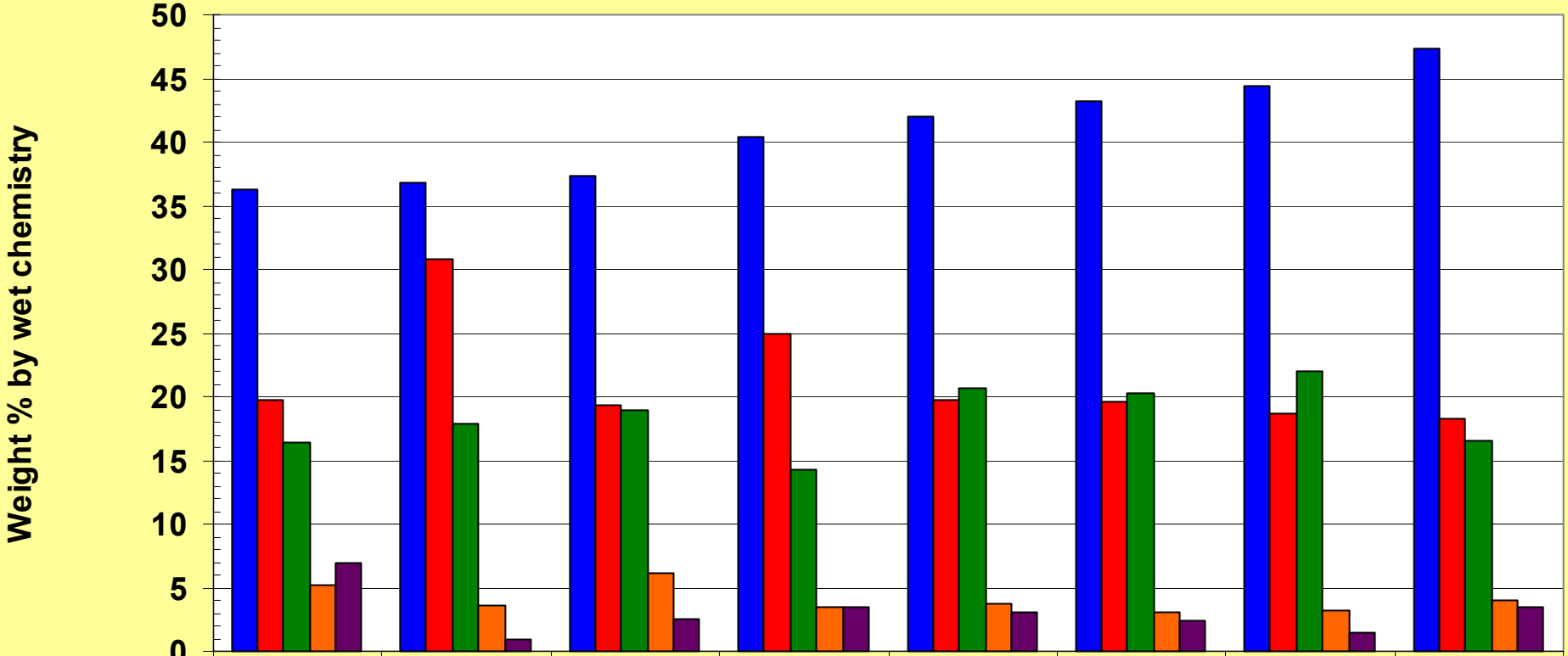
Background

- Stage Gate criteria: Technical feasibility and risk.
- Technical barrier: How diverse is the composition of corn stover, and what are the causes of variability?

- The chemical composition of corn stover is variable.
  - FY01: 8% range in glucan + xylan content
- Carbohydrate content determines maximum ethanol yield, which is a major factor in process economics.
  - FY01: $0.20/gal range in MESP
- Control over feedstock quality can benefit process economics.

Stover Anatomical Fractions



	sheath	cob	node	leaf	whole stover	internode	rind	pith
glucan	36.3	36.8	37.4	40.4	42.1	43.2	44.4	47.4
xylan	19.7	30.8	19.4	25.0	19.8	19.6	18.7	18.3
lignin	16.4	17.9	18.9	14.3	20.6	20.3	22.0	16.5
protein	5.2	3.6	6.2	3.5	3.8	3.1	3.2	4.0
inorganics	6.9	0.9	2.5	3.5	3.1	2.4	1.5	3.5
glucan + xylan	50.7	65.5	50.2	61.8	58.1	58.3	59.3	58.0

Fraction

FY02 Project Goals

- Measure the extent of compositional variability in corn stover from genetically and geographically diverse commercial hybrids.
- Calculate the effect of observed compositional variability on process economics.
- Determine whether genetic and/or environmental factors influence stover composition.

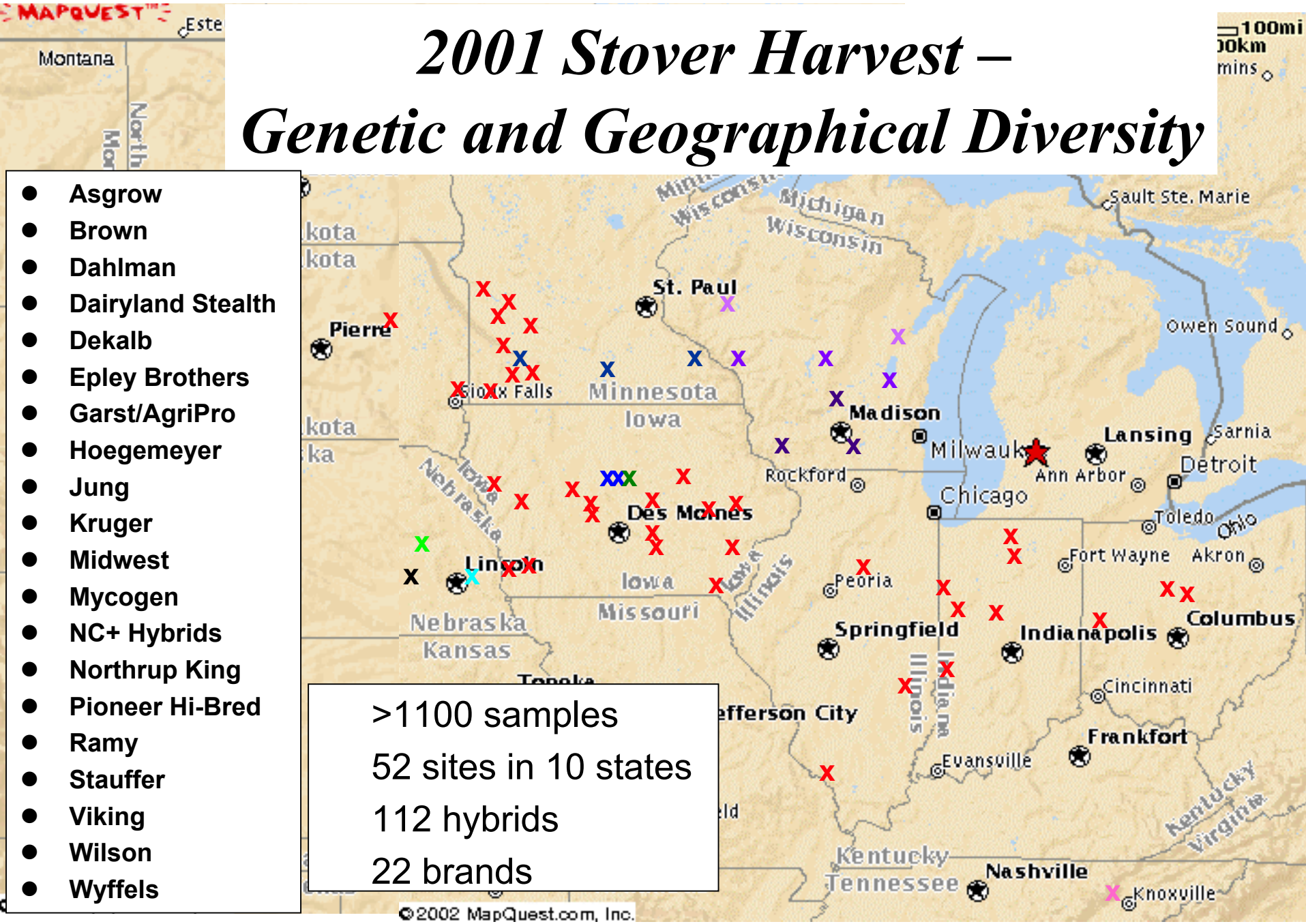
NIR Rapid Analytical Method 'Stover5C'

Constituent	Method Error (Wt%)
Total glucan	1.5
Structural glucan	1.4
Xylan	1.4
Lignin	1.2
Protein	1.0
Acetyl	0.5
Arabinan	1.5
Galactan	1.5
Mannan	1.5
Uronic Acids	1.0
Structural inorganics	1.0

47 calibration samples

Average mass closure
98.2 ± 3.2%

2001 Stover Harvest – Genetic and Geographical Diversity

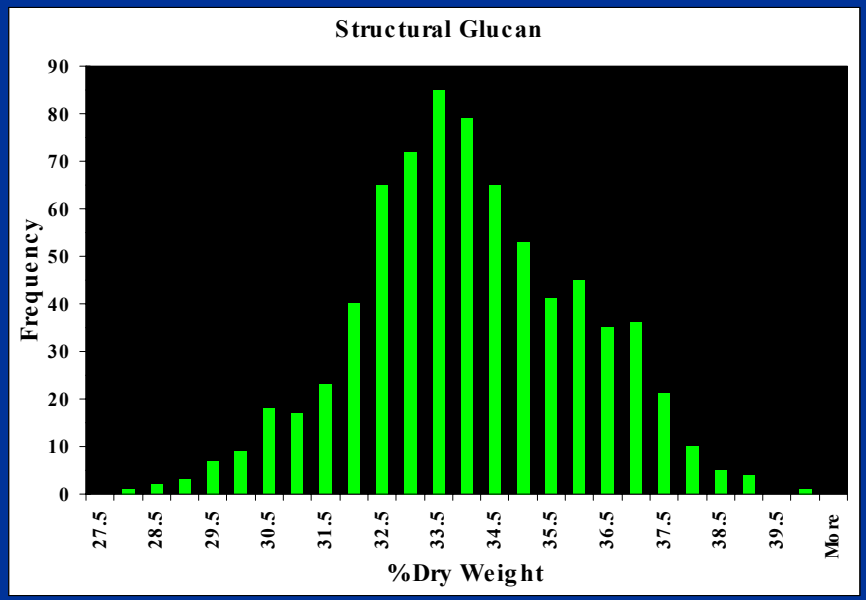


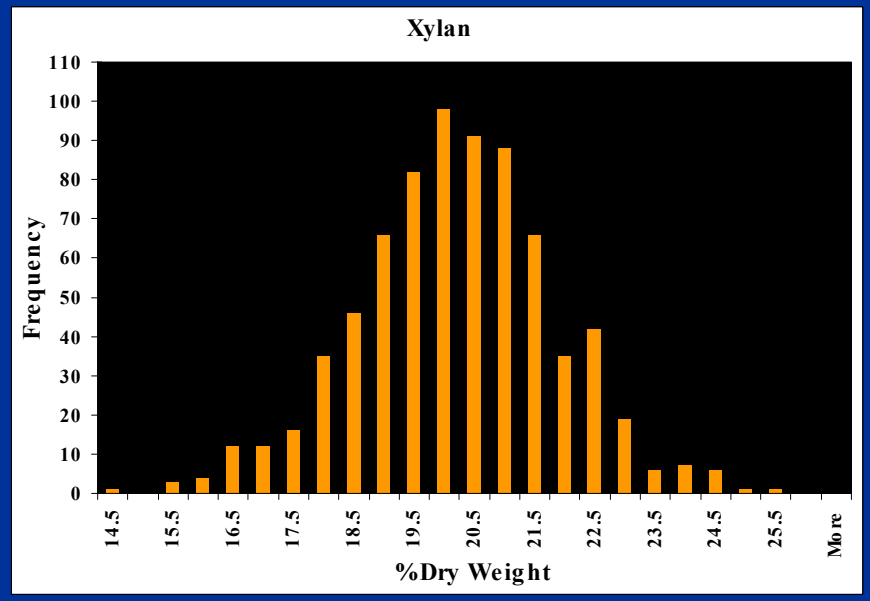
- Asgrow
- Brown
- Dahlman
- Dairyland Stealth
- Dekalb
- Epley Brothers
- Garst/AgriPro
- Hoegemeyer
- Jung
- Kruger
- Midwest
- Mycogen
- NC+ Hybrids
- Northrup King
- Pioneer Hi-Bred
- Ramy
- Stauffer
- Viking
- Wilson
- Wyffels

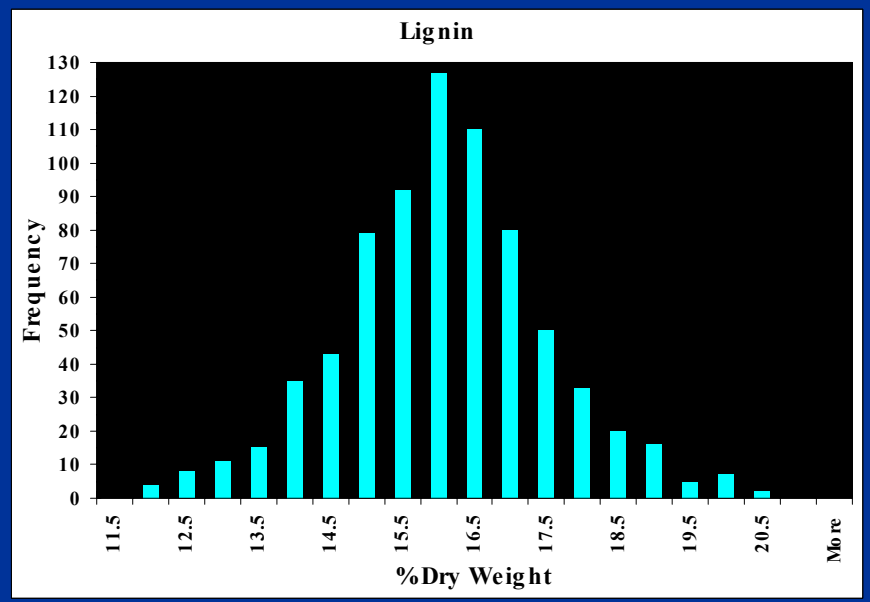
Summary Statistics (n=738)

	Struc_ glucan	Xylan	Lignin	Structural Inorganics (Silica, Ash)	Soluble Solids	Mass Closure	Struc_ glucan + Xylan	Total Structural CHO (5 sugars)
Minimum (%DW)	27.9	14.5	11.5	-1.2	2.0	90.0	43.3	45.3
Maximum (%DW)	39.6	25.5	20.4	10.2	19.6	101.9	63.3	68.5
Range (%DW)	11.7	11.0	8.9	11.3	17.5	11.9	19.0	23.2
Mean (%DW)	33.8	20.0	15.8	4.2	8.2	97.4	53.8	58.7
Standard Deviation (%DW)	2.0	1.6	1.4	1.6	2.2	1.7	2.8	3.2
Coeff. Variation (%)	5.9	8.0	8.9	38.1	26.8	1.7	5.2	5.5

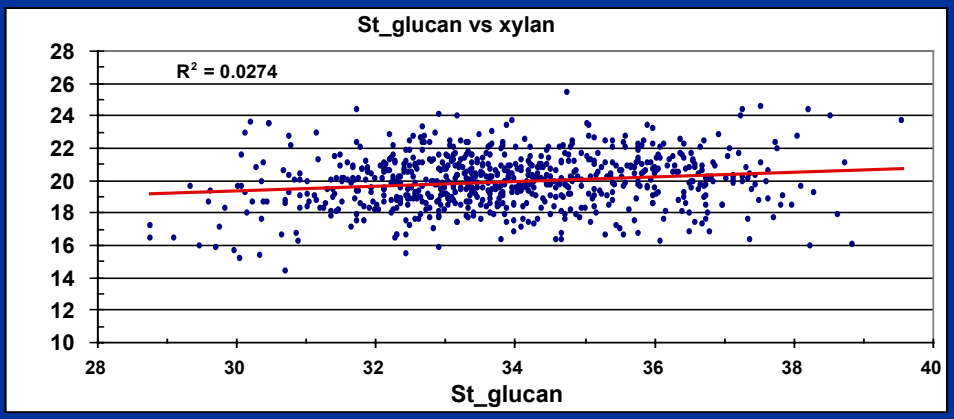
Population Distributions (n=738)

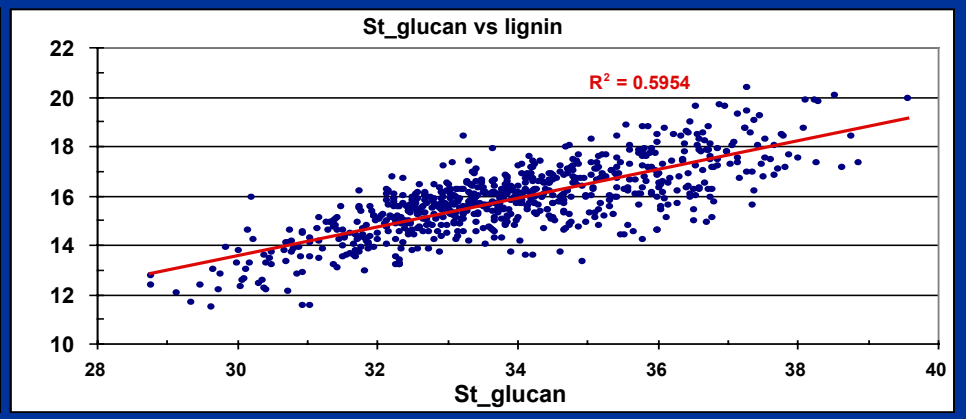






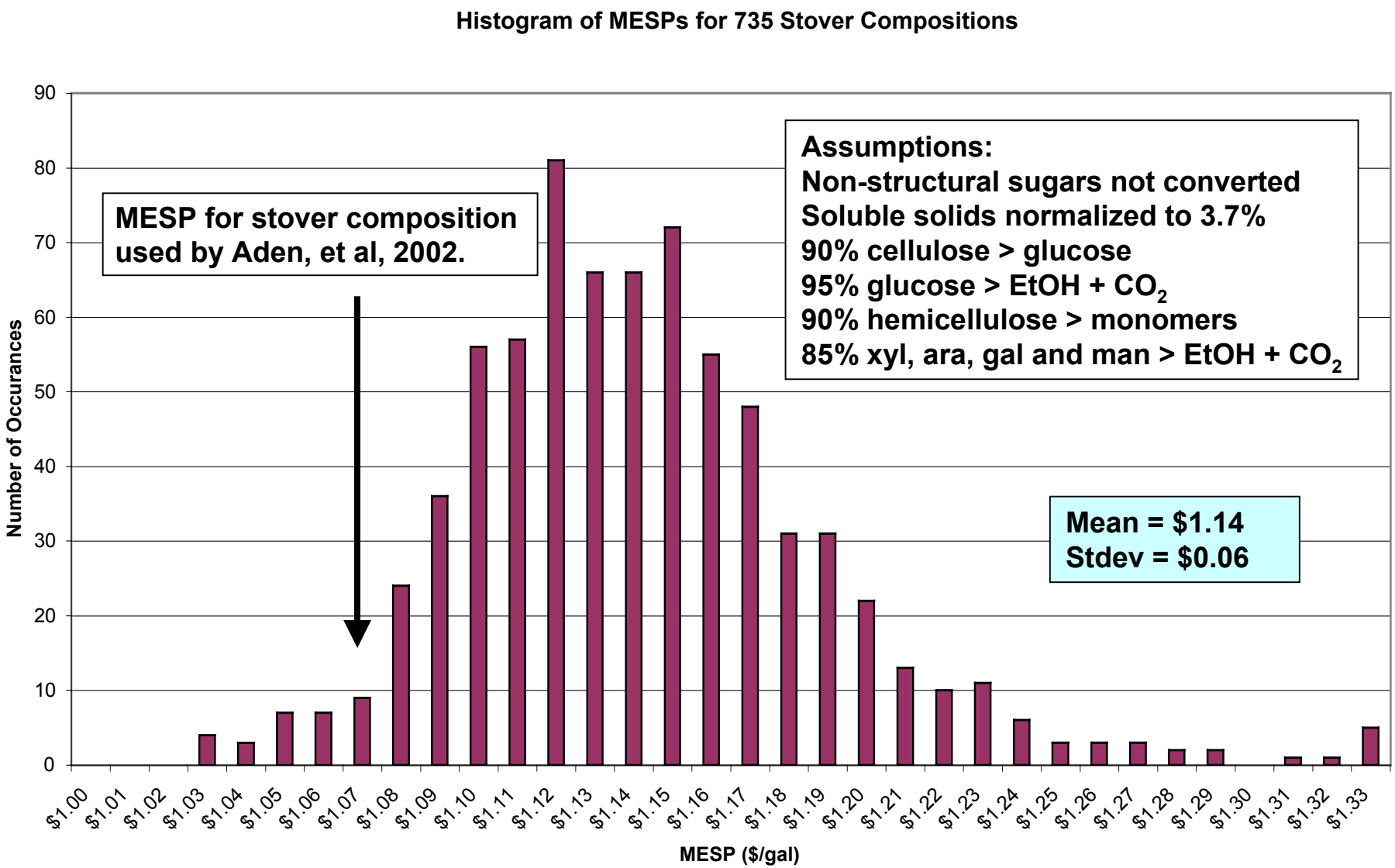
Constituent Pairs Not Correlated





R^2	Glucan	Xylan	Lignin	Protein	Acetyl
Xylan	0.03				
Lignin	0.60	0.16			
Protein	0.70	0.18	0.32		
Acetyl	0.19	0.02	0.15	0.10	
Str_inorg	0.10	0.41	0.32	0.13	0.12

Effect of Stover Composition on MESP



ANOVA: University of Wisconsin

Example: structural glucan

Hybrid	Replicate	Galesville, WI	Fond du Lac, WI	Hancock, WI
Dekalb DKC51-88	1	32.76	33.66	32.57
	2	34.29	33.85	32.67
	3	32.22	34.33	33.39
Mycogen 4111	1	32.24	34.13	34.39
	2	33.36	34.00	33.59
	3	31.26	34.66	33.92
Northrup King N58-D1	1	32.44	35.77	33.09
	2	32.12	35.56	31.86
	3	31.77	35.10	31.93
Pioneer 37H26	1	32.14	35.24	32.18
	2	32.99	33.54	32.70
	3	31.30	35.12	33.16

Summary of ANOVA results (P-values)

Constituent	Genetics	Environment	Interaction
Struc_glucan	0.744	1.04E-07	0.010
Xylan	0.015	4.30E-08	0.903
Lignin	2.02E-05	0.469	0.029
Protein	0.545	1.98E-08	0.135
St_inorg	0.008	4.97E-06	0.142
Struc_glucan + Xylan	0.181	8.38E-06	0.175

ANOVA: Two-factor with replication — Struc_glucan

Source of Variation	SS	df	MS	F	P-value	F crit
Rows (genetics)	0.5644	3	0.18813	0.41495	0.7438103	3.00879
Columns (environment)	30.6548	2	15.3274	33.8064	1.04E-07	3.40283
Interaction (G x E)	9.92103	6	1.65351	3.64701	0.0102649	2.50819
Within	10.8813	24	0.45339			
Total	52.0215	35				

ANOVA: USDA/ARS, Lincoln

Example: xylan

Hybrid	Replicate	Non-irrigated No fertilizer	Non-irrigated fertilizer	Irrigated No fertilizer	Irrigated fertilizer
Pioneer 3162	1	16.31	17.42	20.01	19.60
	2	19.01	15.24	20.98	17.67
	3	17.90	21.22	20.69	20.27
Pioneer 3394	1	17.39	18.14	20.23	17.21
	2	18.63	19.89	17.62	17.55
	3	20.71	17.97	20.82	20.35
Pioneer 33R88	1	18.98	17.74	19.97	14.44
	2	18.21	18.99	16.88	14.93
	3	19.32	20.22	20.83	16.71
Pioneer 34G82	1	20.85	16.25	19.27	12.58
	2	17.13	18.75	19.54	13.33
	3	20.45	19.36	19.92	13.24
B73 x Mo17	1	20.66	19.72	18.47	17.82
	2	17.64	18.80	16.83	17.60
	3	18.87	19.16	18.55	

Constituent	Genetics	Environment	Interaction
Struc_glucan	1.06E-07	1.28E-05	0.175
Xylan	0.148	5.81E-05	0.003
Lignin	0.002	0.062	0.112
Protein	1.46E-06	9.48E-11	0.435
St_Inorg	0.171	0.355	0.014
Struc_glucan + Xylan	0.001	0.002	0.086

ANOVA: Two-factor with replication — Xylan

Source of Variation	SS	df	MS	F	P-value	F crit
Rows (genetics)	14.8383	4	3.70957	1.79713	0.14845	2.60597
Columns (treatments)	60.4766	3	20.1589	9.7661	5.8E-05	2.83875
Interaction	78.5386	12	6.54488	3.17072	0.00298	2.00346
Within	82.5666	40	2.06417			
Total	236.42	59				

Conclusions

- Corn stover composition spans a wide range of total structural carbohydrates.
  - Range = 23.2% (Glc + Xyl + Ara + Gal + Man)
- The impact of observed compositional variation on MESP is up to $0.30/gal. Average MESP ~$1.14/gal.
- Assumptions about the average composition of corn stover for techno-economic modeling should be revised.
- The computed “mean composition” does not correspond to any sample in the database.
- Paired constituent values do not correlate well. Constituents vary nearly independently of one another.
- Stover composition is influenced by both genetic and environmental factors.
  - Any ability to manage or control stover composition could have beneficial effects on process economics.

Recommendations for Future Work Near-term

Technical feasibility ⟶ Risk reduction

- Periodically monitor genetically and environmentally diverse commercial stover samples.
  - Include more corn growing states, more hybrids and newer hybrids.
- Widen the germplasm base surveyed to determine whether genetic resources could be valuable in breeding programs directed at stover quality (~400 non-commercial variety samples on-hand).
  - Partner with USDA's National Plant Germplasm System.
- Cultivate stakeholder relationships with corn breeders and agronomists at public and private institutions.
  - NSF-funded Cell Wall Project.

Recommendations for Future Work Long-term

Technical feasibility → Risk reduction

- With USDA, plan and execute a series of field studies to determine the major genetic and environmental factors influencing stover quality.
  - Partner with universities and seed companies
- Develop tools and methods to detect differences in cell wall architecture that may be responsible for differential processing performance.
  - Antibody probes
  - Enzyme probes
  - Microscopy
  - NMR, Raman and other chemical techniques

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